The Influence of Sinonasal Anatomy on Upper Airway Allergies

Trisha Saha Ray MD[1], Lirit Levi MD[2], Vivek Mohan,MS[3], Yifei Ma MS[2], Christopher Meliadis MD[5], Paramesh Gopi PhD[3], Jayakar Nayak MD[2], Bryant Lin MD[2], Peter Hwang MD[2], Jacob Johnson MD[5], Kari Nadeau MD PhD[1], Michael Blaiss MD4

HARVARD MEDICAL SCHOOL

Stanford MEDICINE Otolaryngology Head and Neck Surgery

Introduction

Allergic rhinitis affects roughly 20% of the world population. It leads to a variety of related quality of life disturbances including impairments in day- time productivity and lower quality of sleep. As a result, the economic burden associated with Allergic Rhinitis and its related causes is substantial.

This study explores the relationship between nasal anatomy and allergic rhinitis. It connects the anatomy and physiology of the sinonasal cavity and nasal structures to the occurrence and severity of allergic rhinitis symptoms.

Intranasal Pollen Deposition Model

- Our work builds upon previous CFD (Computational Fluid dynamic) models and particle deposition research that has been used to predict intranasal particle deposition based on particle size and normal respiration and linear laminar flow[2.]
- We use an Impaction Parameter (IP) which follows the Navier Stokes Model to establish the following relationship

  IP = Particle_Diameter × Breathing Rate

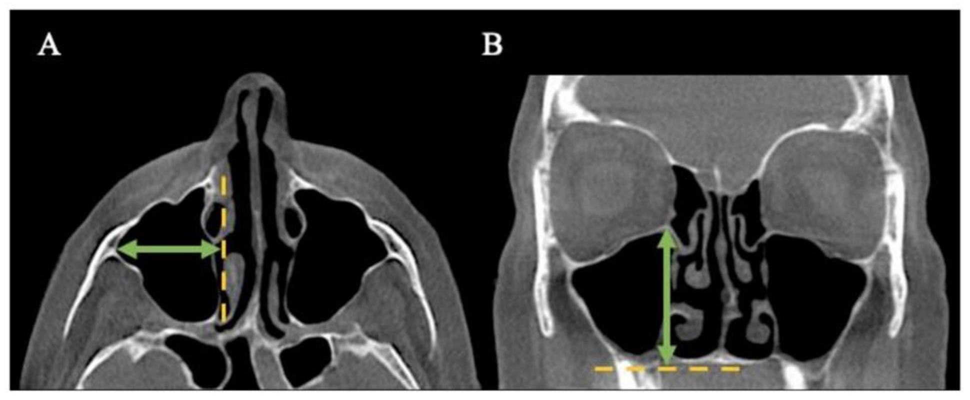
- Particle Sizes: 25-100 microns (grass, weed, tree)
- Main deposition areas: Kiesselbach's Plexus, Vestibule, Inferior and Middle Turbinate, Central Nasal Airway
- Allergic symptoms driven by Cytokinetics which is a function of deposition efficiency (# of particles)i

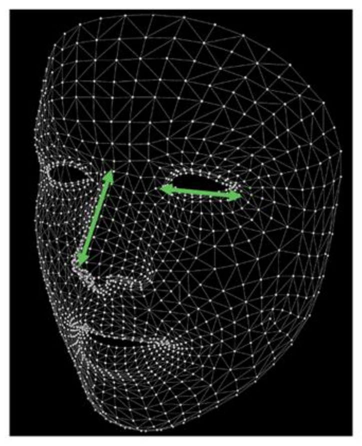
Methods

- We conducted a retrospective review of medical records from a 2363 patients across a period of 9 months in the continental United States in 2024.
- All patients used The SONU[1] device, an FDA-approved acoustic resonance therapy (ART) band, which uses a smartphone-based system for facial scanning and a machine learning (ML) algorithm to estimate internal and external sinonasal anatomy to within 95% accuracy of a CT Scan[3]. All ART users are patients with at least mild congestion based on TNSS scores evaluated prior to ART treatment.
- Our data included detailed session duration, date, time and air quality index geo-tagging for each patient.
- We used a second set of 26 patients with CT Scans (as opposed to ART app scan) to derive a clinically useful threshold for DHR versus nasal congestion symptoms for effective prognostication.

Parametric Predictive Model

- We estimated the **Depth to Height Ratio (DHR)** from nasal cavity dimensions provided by the app for each patient. We recorded the number of therapy sessions each patient completed between with each session defined as two consecutive uses of the device lasting 5 minutes each.
- We used Usage telemetry as a proxy for nasal symptoms.
- Session count was designated as the primary outcome variable that was tracked and analyzed across the entire cohort longitudinally.
- Given the physics and CFD assumptions, we set out to test the hypothesis that usage, i.e. symptoms, and therefore device usage would be related to DHR





Real vs Estimated	Width	Height
Absolute Error	0.139 ± 0.084 cm	0.252 ± 0.191 cm
Percent Error	4.13 ± 2.44 %	6.38 ± 4.79 %

Meliadis et al, EMBS 2023

Results

- Patients across the cohort (male and female) with DHR > 1.5 were the most frequent users of the ART band
- The use (sessions and time) of the ART therapy was statistically significant with a p value < 0.001 across both male and female populations with DHR > 1.5

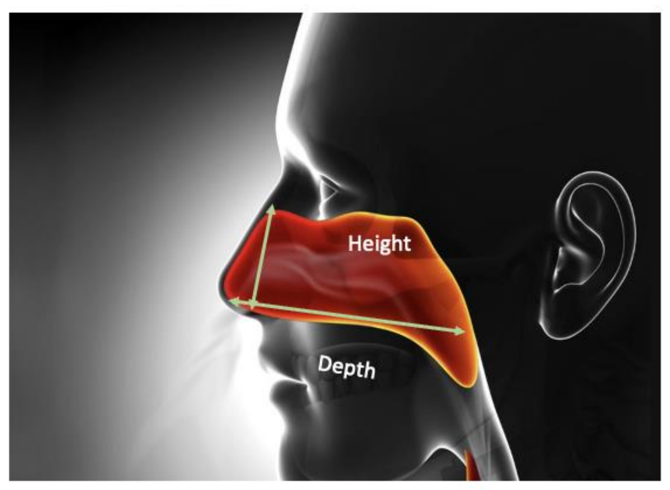
	Male		Female		Interaction effect	
	Odds ratio (95% CI)	p-value	Odds ratio (95% CI)	p-value	Odds ratio (95% CI)	p-value
DHR>=1.5						
session_per5	1.281 (1.132, 1.45)	<.0001	327.711 (46.996, 2285.18)*	<.0001	0.004 (0.001, 0.03)	<.0001
minute_per10	1.032 (1.015, 1.049)	<.0001	2.534 (1.838, 3.49)	<.0001	0.407 (0.295, 0.56)	<.0001
day_per10	0.998 (0.984, 1.012)	0.760	0.998 (0.985, 1.01)	0.748	1 (0.981, 1.02)	0.996

- Nasal Cavity Depth and Height drive Pollen Impaction (Particle Physics)

Nasal Cavity Depth	Deep	Shallow
Pollen Transit Time	Increases	Reduces
Impaction	High	Low

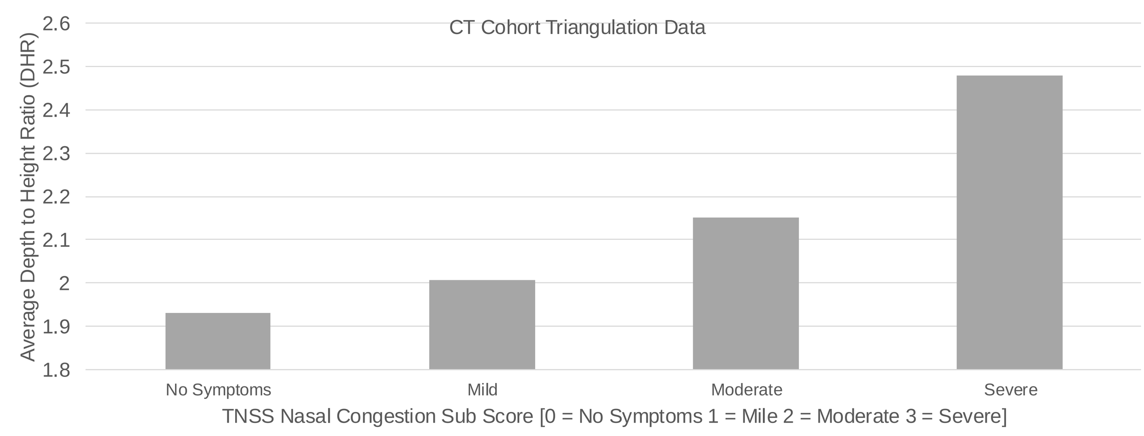
Nasal Cavity Height	Tall	Short
Pollen Density	Decreases	Increases
Impaction	Low	High

- More Pollen → More Nasal Allergies
- DHR = Depth / Height Ratio
  - Anatomical Marker (Craniofacially derived based on CT ML trained data set)



Discussion

- Our results are supported by prior investigations on nasal flow dynamics, that demonstrate that nasal geometry significantly influences particle deposition.[4] Controlled studies[5] in allergen exposure chambers demonstrate a direct dose-response relationship between airborne pollen concentrations and allergic symptoms. Grass pollen challenges showed that concentrations as low as 3,000 particles per cubic meter (p/m³) triggered nasal and ocular symptoms, with 8,000 p/m³ producing consistent, measurable responses across total nasal symptom scores (TNSS). Higher pollen concentrations correlate with accelerated allergen release from grains and increased IgE-mediated immune activation, amplifying symptom severity.
- DHR simplifies allergic rhinitis assessment by combining two critical factors affecting nasal airflow and particle deposition fractions. Previous studies indicate that a lower minimum cross-sectional area correlates with higher deposition efficiency due to high velocity and increase wall shear stress and resistance[6]. Secondly, the depth of the nasal cavity affects the transit time of particles, thus impacting deposition efficiency, as indicated by research showing increased particle deposition with greater cavity depth[21].   A confirmatory analysis of 26 CT scans of patients with higher DHR reported higher Nasal Congestion TNSS Subscores.



References

[1] Luong AU, Yong M, Hwang PH, et al. Acoustic resonance therapy is safe and effective for the treatment of nasal congestion in rhinitis: A randomized sham-controlled trial. Int Forum Allergy Rhinol. 2024; 14: 919–927.
[2] Mohammad Hazeri, Mohammad Faramarzi, Sasan Sadrizadeh, Goodarz Ahmadi, Omid Abouali, Regional deposition of the allergens and micro-aerosols in the healthy human nasal airways, Journal of Aerosol Science, Volume 152,
[3] C. Meliadis et al., "Estimating Maxillary Sinus Volume Using Smartphone Camera," in IEEE Open Journal of Engineering in Medicine and Biology, vol. 6, pp. 256-260, 2025, doi: 10.1109/OJEMB.2024.3516320.
[4] Sedghy F, Varasteh AR, Sankian M, Moghadam M. Interaction Between Air Pollutants and Pollen Grains: The Role on the Rising Trend in Allergy. Rep Biochem Mol Biol. 2018 Apr;6(2):219-224. PMID: 29766006; PMCID: PMC5941124.
[5] Kosowska A, Zemelka-Wiącek M, Smolińska S, Wyrodek E, Adamczak B, Jutel M. Clinical validation of grass pollen exposure chamber in patients with allergic rhinitis triggered by timothy grass. Clin Exp Allergy. 2024 Jul;54(7):489-499. doi: 10.1111/cea.14482. Epub 2024 Apr 14. PMID: 38616622.
[6] Kesavanathan J, Swift DL. Human Nasal Passage Particle Deposition: The Effect of Particle Size, Flow Rate, and Anatomical Factors. Aerosol Science and Technology. 1998;28(5):457-463. doi:10.1080/02786829808965371

Author Affiliations

1 Division of Allergy and Immunology, Beth Israel Deaconess Medical Center, Harvard Medical School, Boston, MA, USA
2 Department of Otolaryngology–Head and Neck Surgery, Stanford University School of Medicine, Stanford, California, USA
3 Sound Health Systems, Los Altos, California, USA
4 UCSF School of Medicine / San Francisco Otolaryngology Medical Group, San Francisco, California, USA
5 Medical College of Georgia, Augusta, Georgia USA

Supplemental Materials: Computational Fluid Dynamic (CFD) Nasal Airflow Models (Courtesy of Zhao et al. Ohio State Univeristy)

HARVARD MEDICAL SCHOOL

Stanford MEDICINE Otolaryngology Head and Neck Surgery

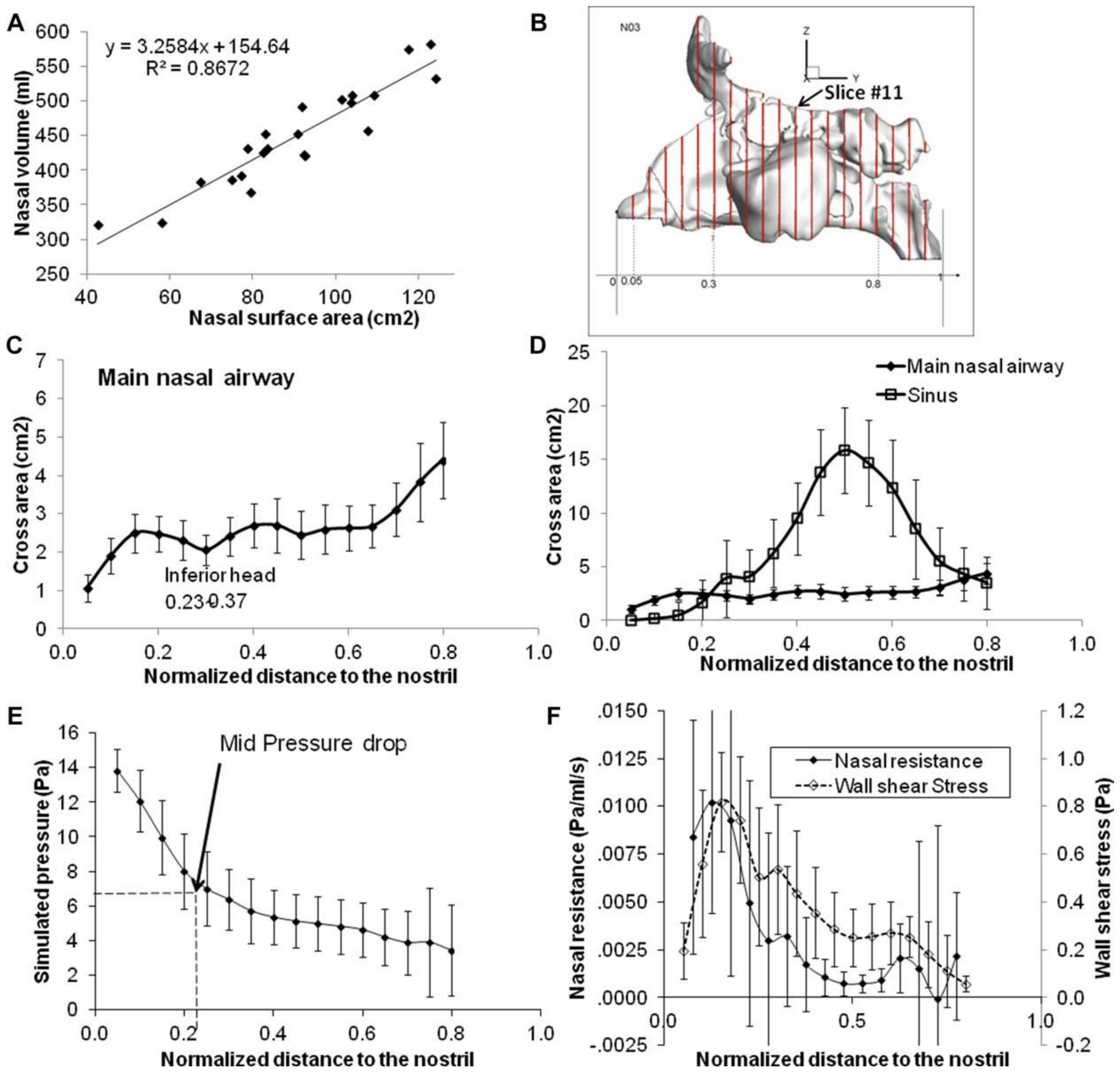


FIGURE 2. (A) Nasal airway volume and surface area (excluding sinus and nasal pharynx) significantly correlate with each other. (B) To account for difference in overall lengths of different individual, each nasal cavity is sectioned into 19 uniformly spaced coronal planes. The average length of nasal cavity was 11.2 cm, and each plane was spaced on average 0.56 cm. The last three coronal sections that cut through the nasopharynx region were excluded from the analysis. (C, D) Average and standard deviation of cross-sectional area of main nasal airway (A) and sinus (B) of the CFD models as a function of normalized distance to the nostril. Average (area-weighted) and standard deviation of pressure drop (E), regional nasal resistance and wall shear stress (F) as a function of distance to the nostril. >50% of pressure drop was reached prior to the inferior turbinate head. CFD = computational fluid dynamics.

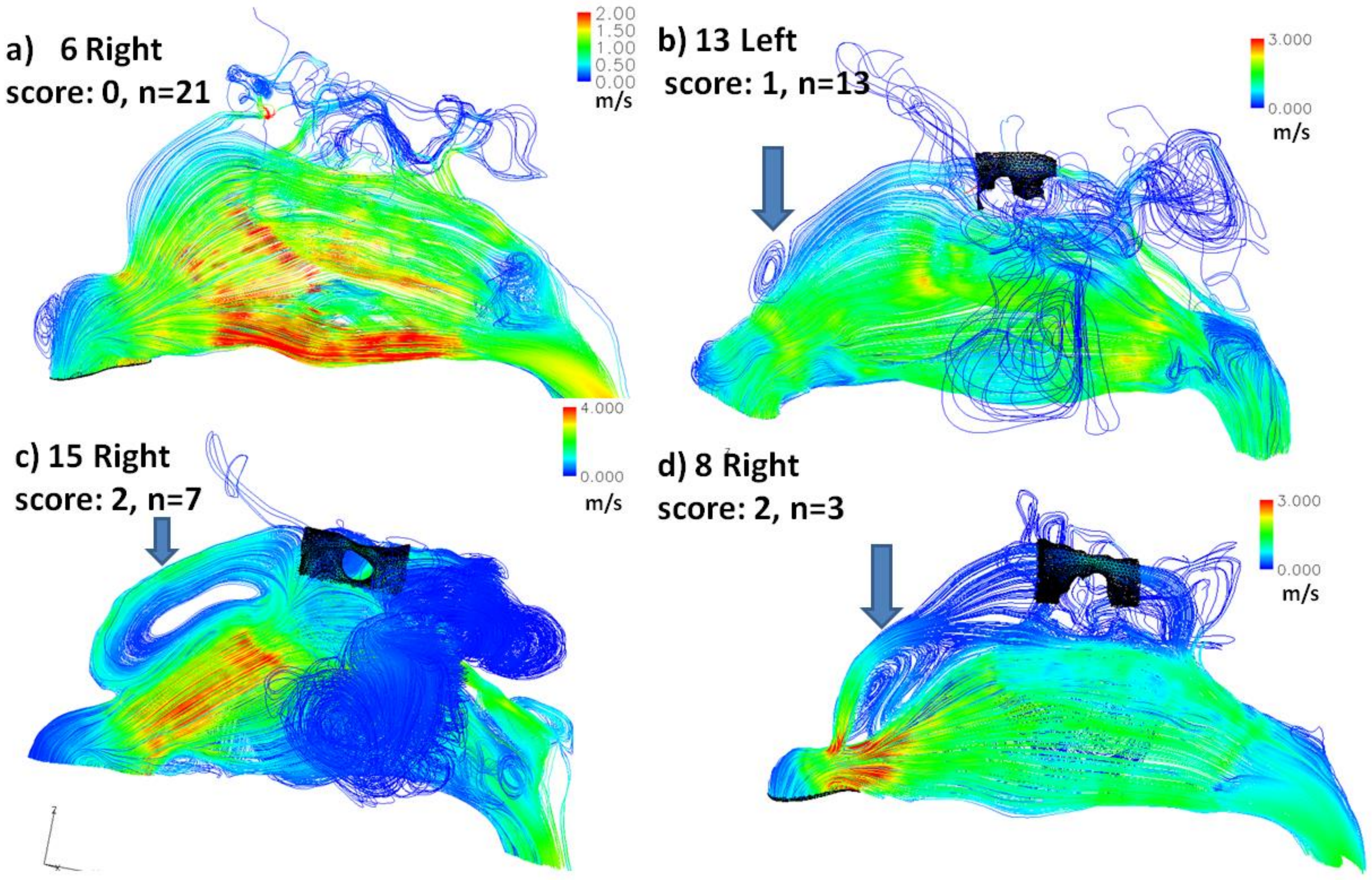


FIGURE 3. Examples of streamline patterns and formation of the anterior dorsal vortex (see arrows) of four subjects: (A) no vortex, (B) a small vortex, (C) a significant vortex, and (D) a significant vortex but in clockwise rotation. The intensity of the vortex is further scored: 0 for no vortex (A), 1 for small vortex (B), 2 for large vortex (C, D); n values indicate the number of sides of all subjects that were categorized into each pattern, which indicated that forming of nasal airflow vortex is quite common among healthy subjects. Black shading indicates the olfactory region. Vortex score was found to significantly correlated with nasal index ($r = -0.46$, $p < 0.05$), indicating that a narrower and talker external nose is more like to have significant flow vortex